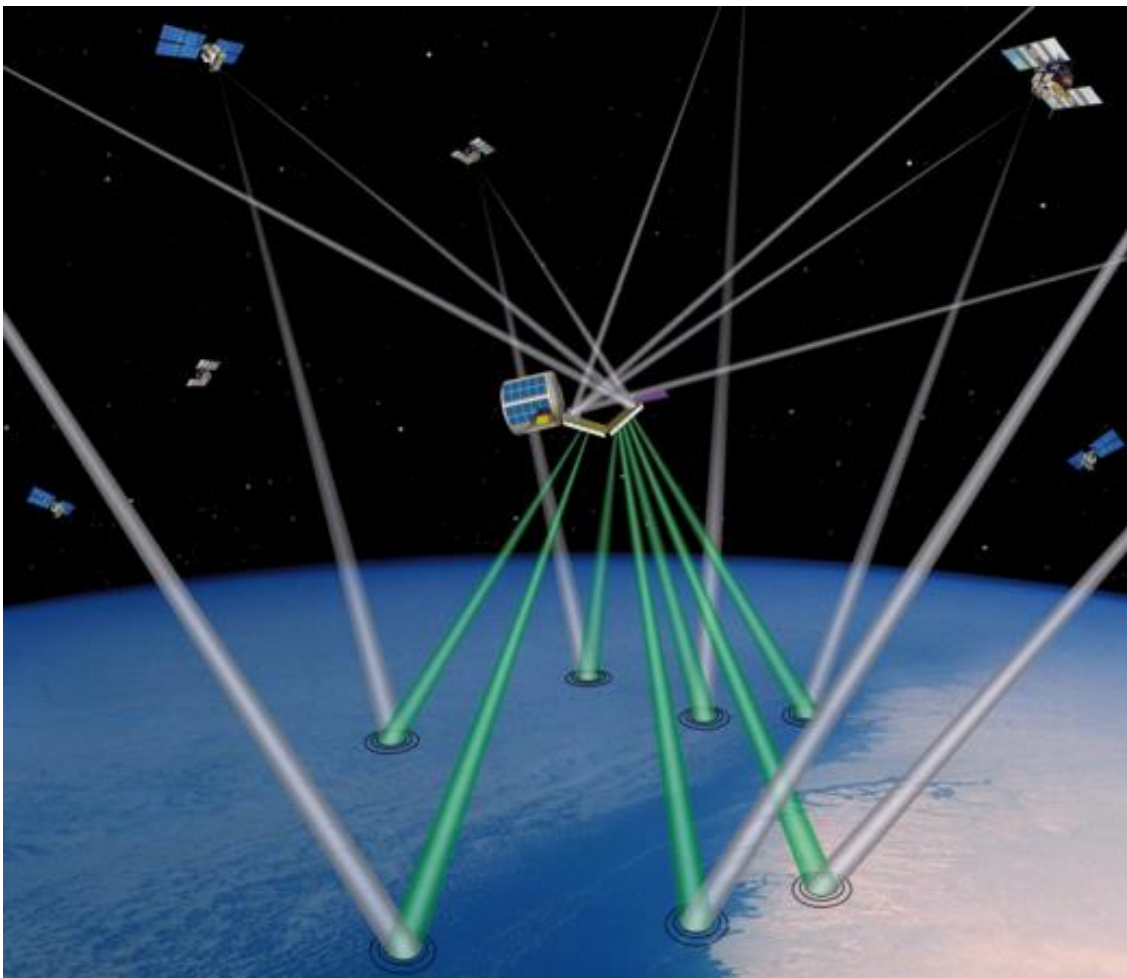


Earth Remote Sensing using Surface-Reflected GNSS Signals (GNSS-Reflectometry)

Stephen T. Lowe (JPL/Caltech)

Presented 11/15/17

Space-Based Positioning, Navigation, and Timing
National Advisory Board



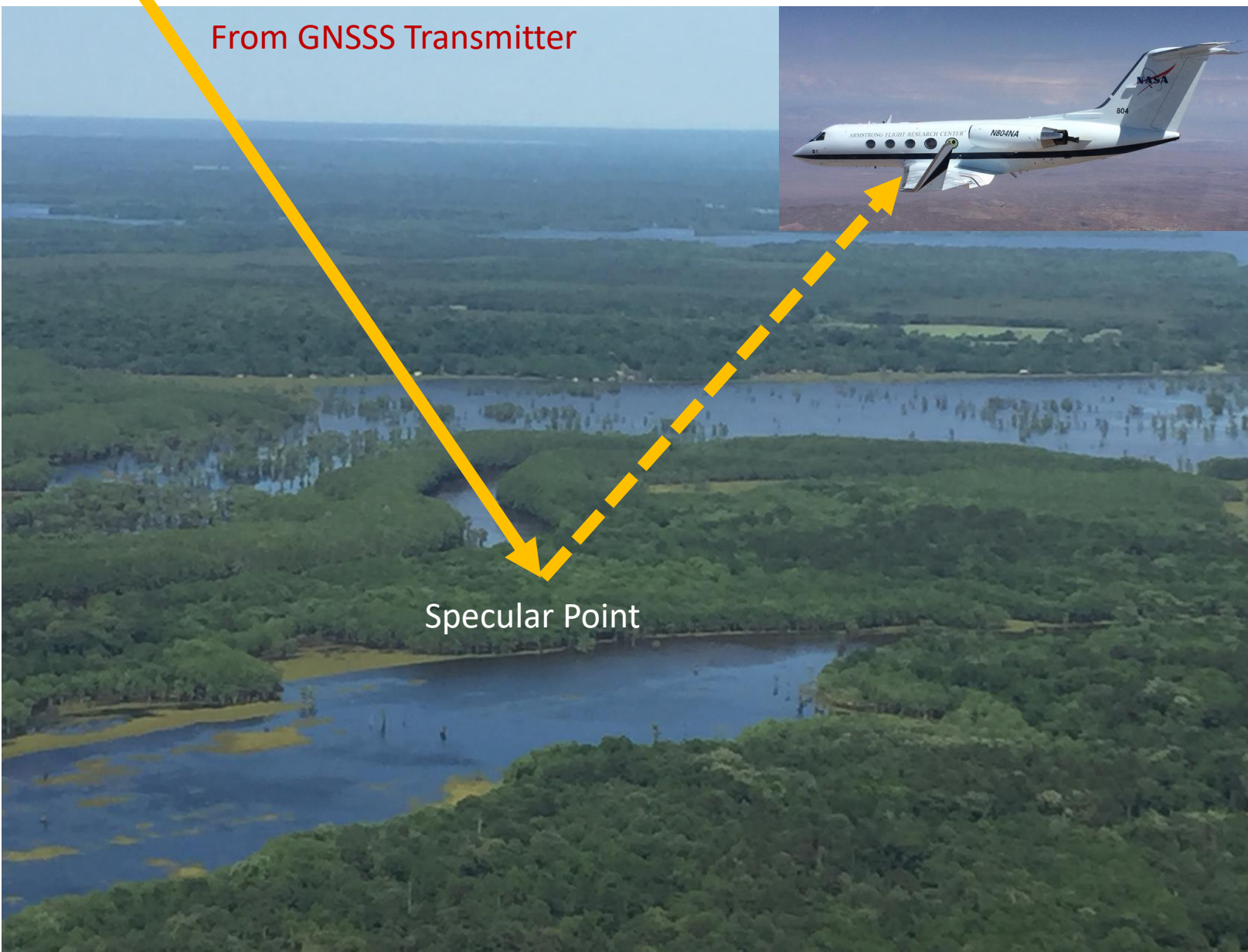
- What is GNSS-Reflectometry (GNSS-R)?
- What measurements can GNSS-R make?
- What's currently happening in this field?

What is GNSS-Reflectometry (GNSS-R)?

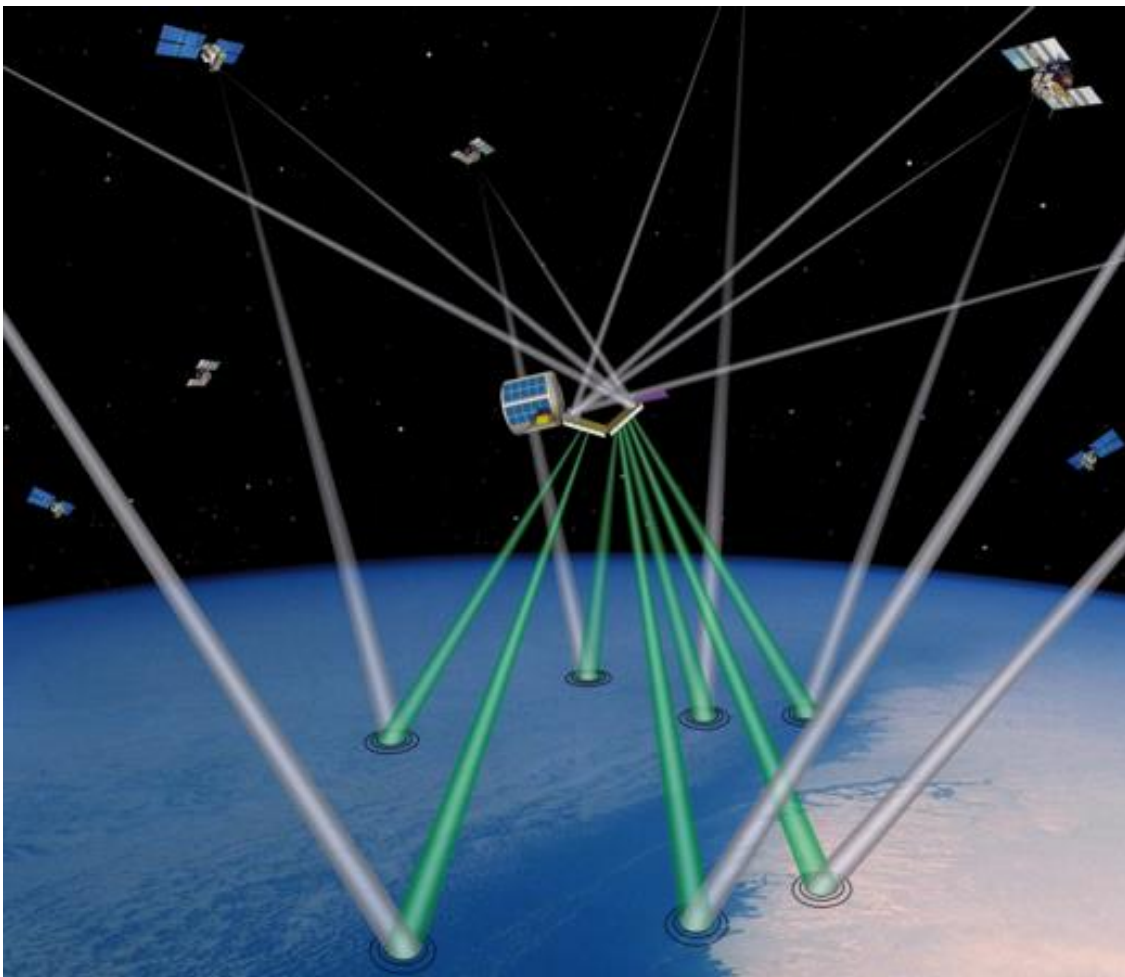


- Radar
 - Monostatic
 - Transmitter & receiver co-located (1)
 - Backscatter

What is GNSS-Reflectometry (GNSS-R)?



- Bistatic Radar
 - Just radar with separate transmitter receiver (2)
 - Forward-scattering
- Power(time)
 - Shape => Roughness
 - SNR => Conductivity
 - Timing => Height

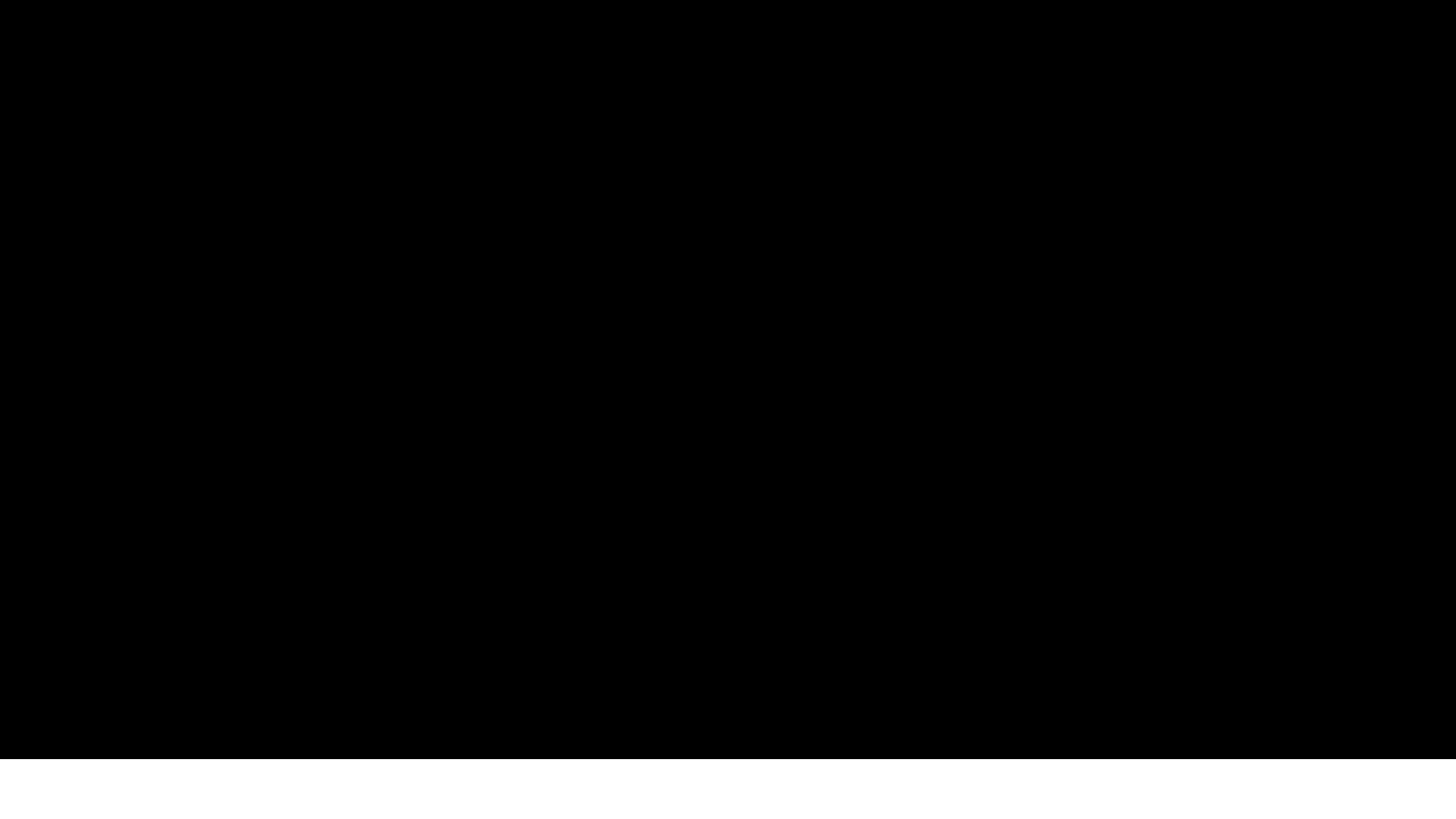


GNSS-R

- Multi-bistatic (multistatic)
- Next few years: >100 GNSS transmitters
- Dense surface coverage

Many Advantages

- Multiple, simultaneous observations
 - High spatial / temporal resolution
- Free high-quality signals
- Leveraging huge global infrastructure
- No transmitter
 - Relatively low cost
 - Constellation possibilities (CyGNSS)
- Forward scattering
- Same hardware as Radio-Occultations'



What Measurements Can GNSS-R Make?

Oceanography

- Surface winds (CyGNSS Mission: Cyclones)
- Mesoscale topology
- Tsunami science/warning
- Geoid / Mean Sea Surface

Red: Demonstrated from space

Green: Future work

Land

- Soil Moisture
- Wetland Extent
- Freeze/Thaw
- Vegetation Characteristics

Cryosphere (assuming high-inclination orbit)

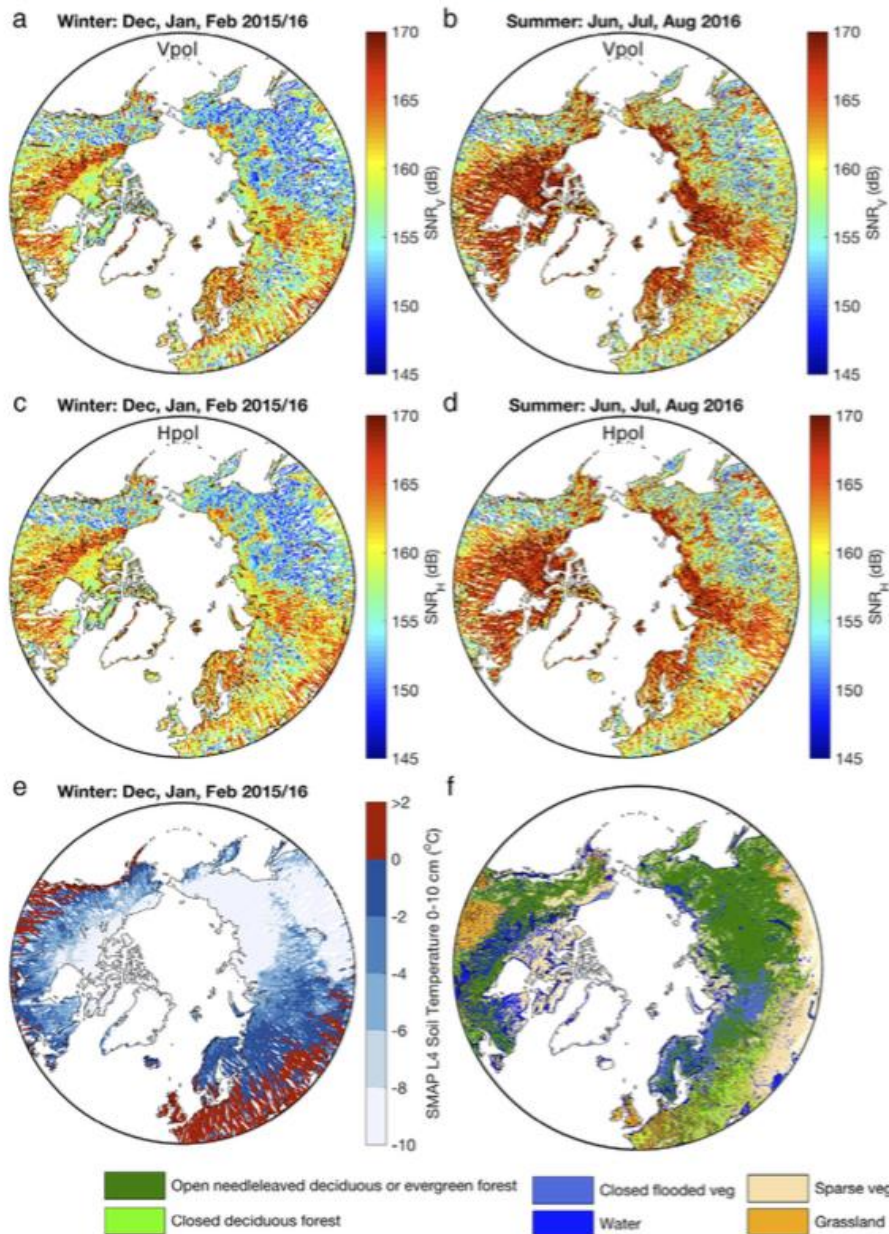
- Sea-Ice Extent
- Ice freeboard
- snow depth
- Ice roughness / age

What's Happening in the GNSS-R Field?

<u>Mission/Satellite</u>	<u>Year</u>	<u># Space GNSS Reflections</u>
SIR-C	2003	2
UK-DMC	2007	22
TechDemoSat1	2015-2017	??
SMAP (GNSS-R)	2015-present	>2.3M + 2900/day
CyGNSS (8 sats)	2017-present	>125M + 0.5M/day

What's Happening in the GNSS-R Field?

C. Chew et al. / Remote Sensing of Environment 198 (2017) 333–344



SMAP GNSS-R Observes Freeze/Thaw

Horizontal Polarization

Winter

Summer

Vertical Polarization

Winter

Summer

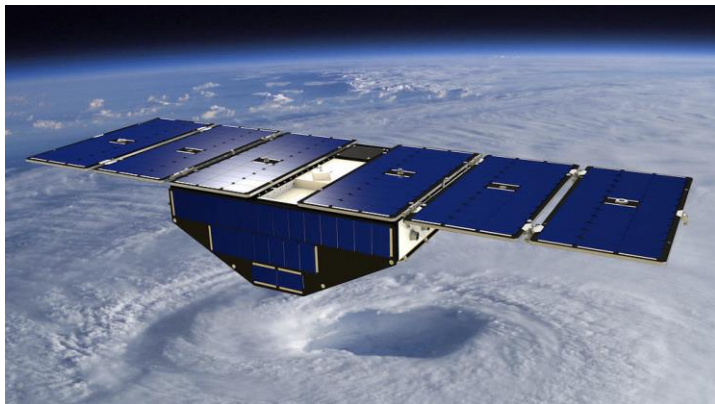
Winter Temp
(blue frozen)

Vegetation Type

From Chew et al, Remote Sen Env 198, 2017

What's Happening in the GNSS-R Field?

CyGNSS Satellite

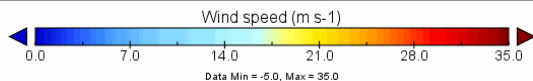
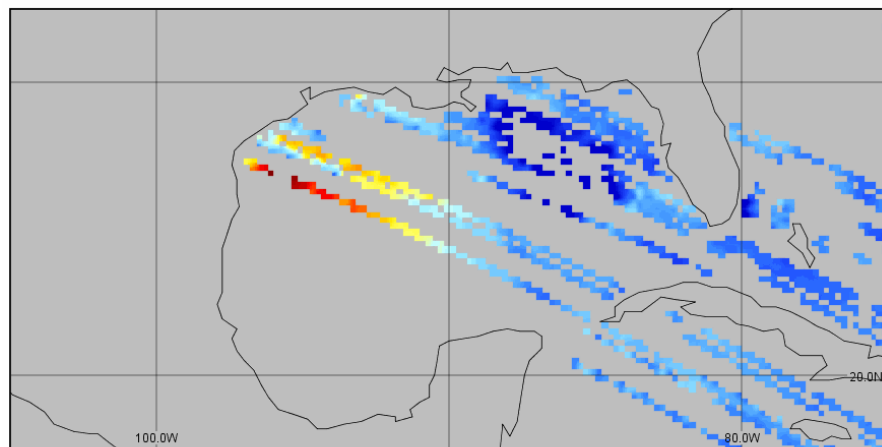


CyGNSS: NASA Earth Venture Mission

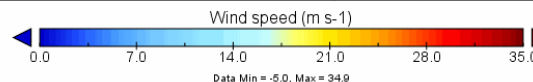
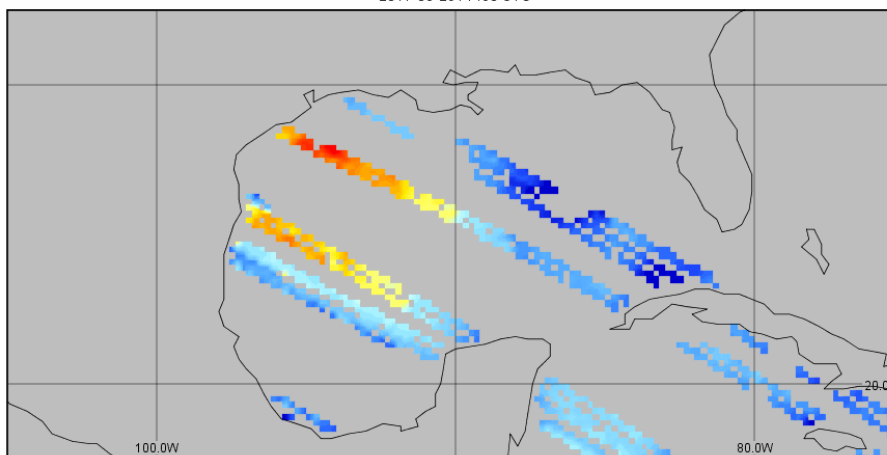
- \$157M to study Cyclone Science
- Goal: Improved cyclone intensity forecast
- 8 small-sats
- Observe GPS L1 C/A signals after reflecting from the ocean

Observations of Hurricane Harvey Prior to Landfall on August 25, 2017

CYGNSS Ocean Surface Wind speed
2017-08-25T1330 UTC



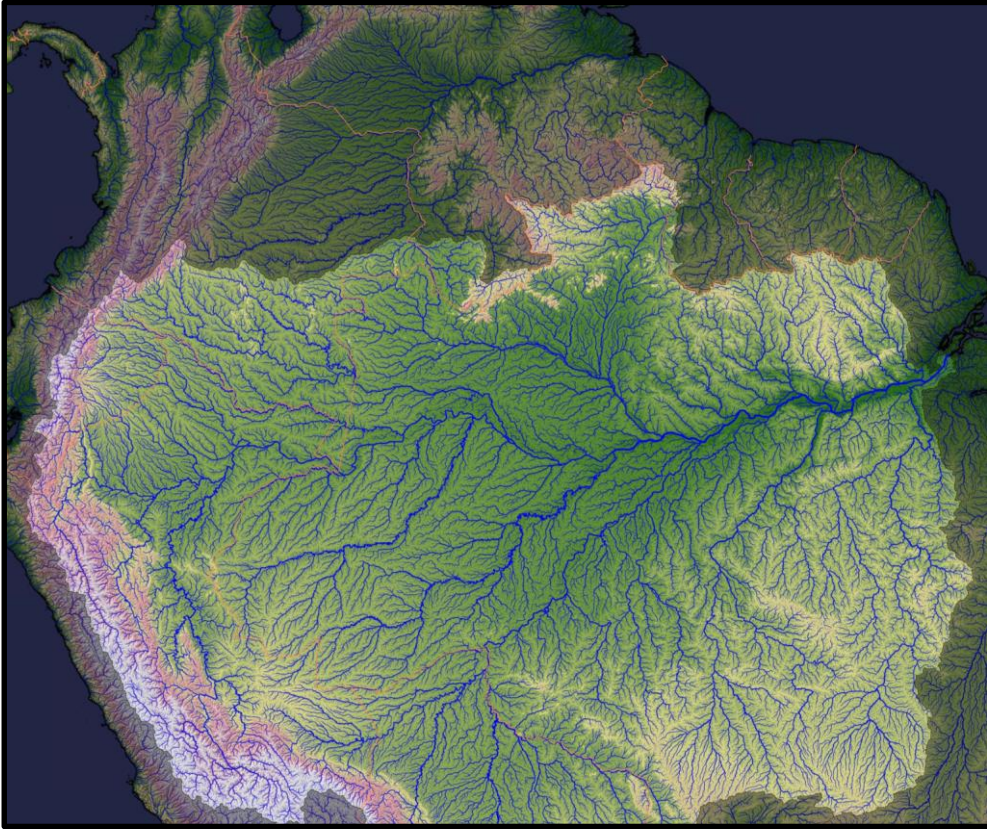
CYGNSS Ocean Surface Wind speed
2017-08-25T1430 UTC



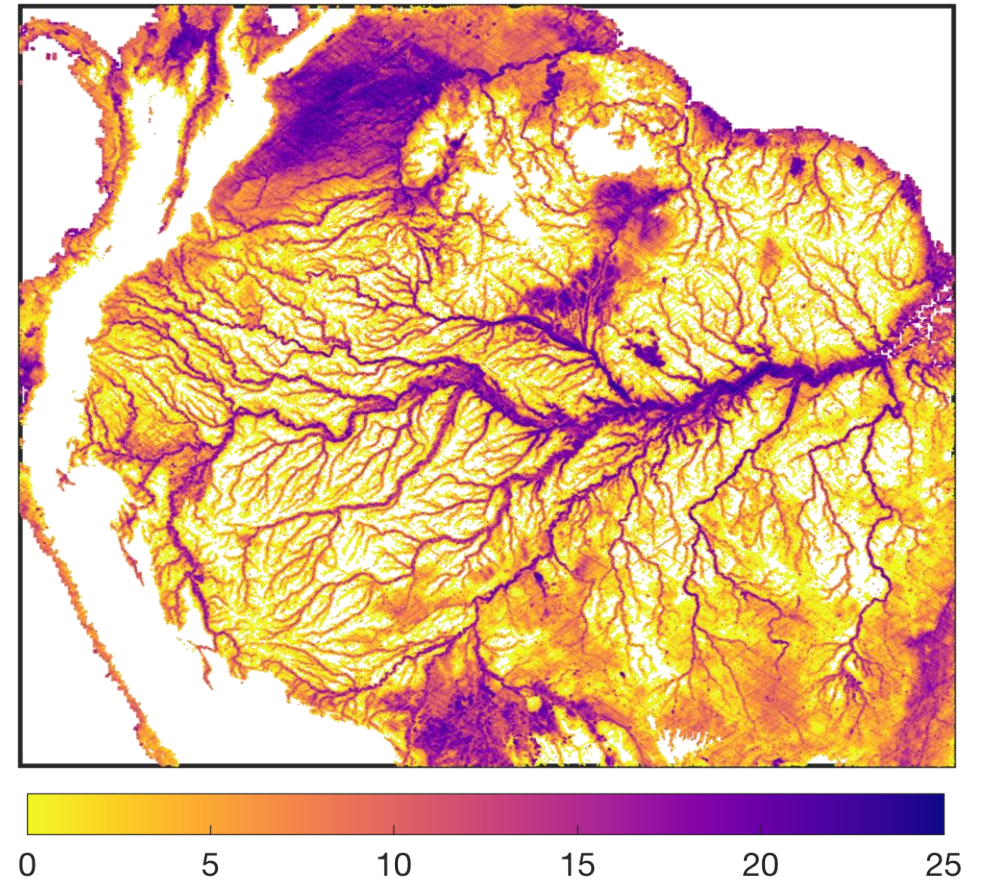
CYGNSS Level 3 gridded surface wind speed data product (v1.1) at
1300-1400 and 1400-1500 UTC on 25 Aug 2017, prior to landfall at ~0300 UTC on 26 Aug 2017

What's Happening in the GNSS-R Field?

HydroSheds Database



CyGNSS Data

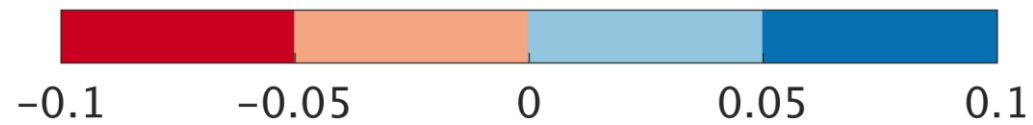
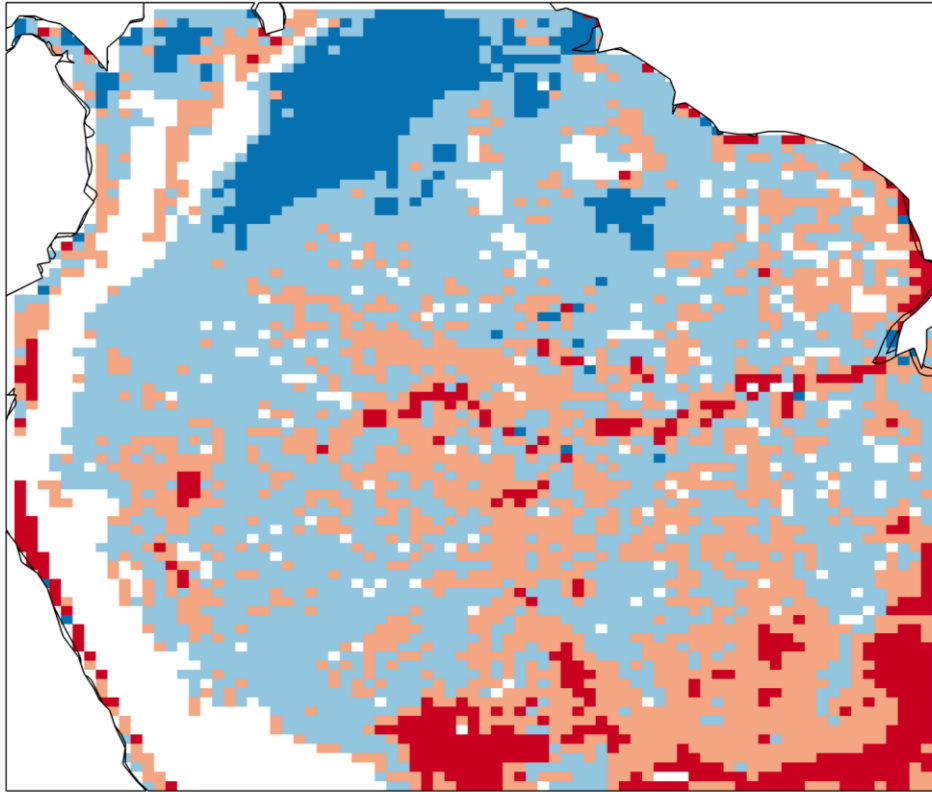


Amazon Rainforest

Courtesy Clara Chew (UCAR)

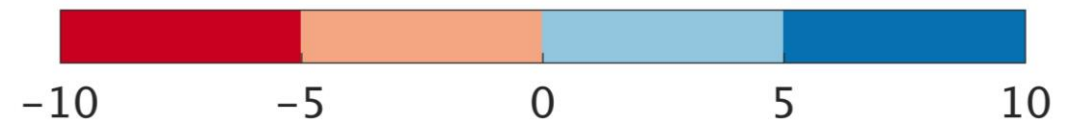
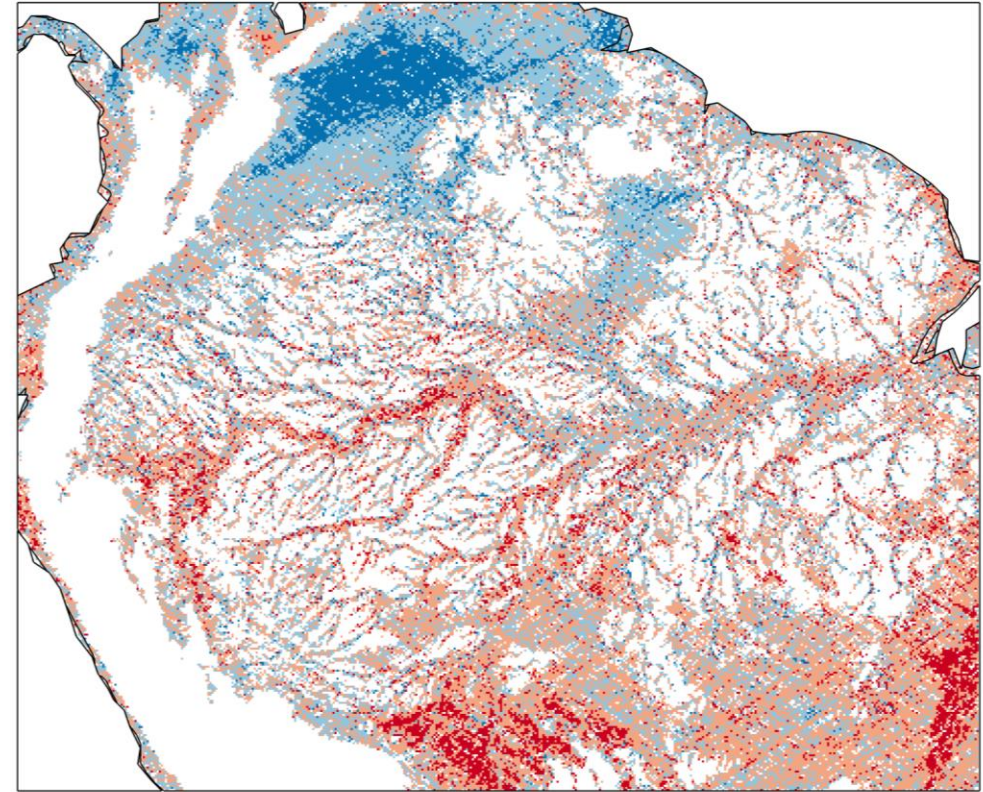
What's Happening in the GNSS-R Field?

SMAP Radiometer



$\Delta \text{Inundation}$

CyGNSS Data



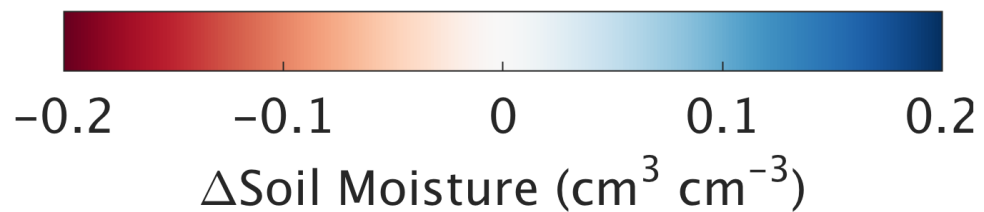
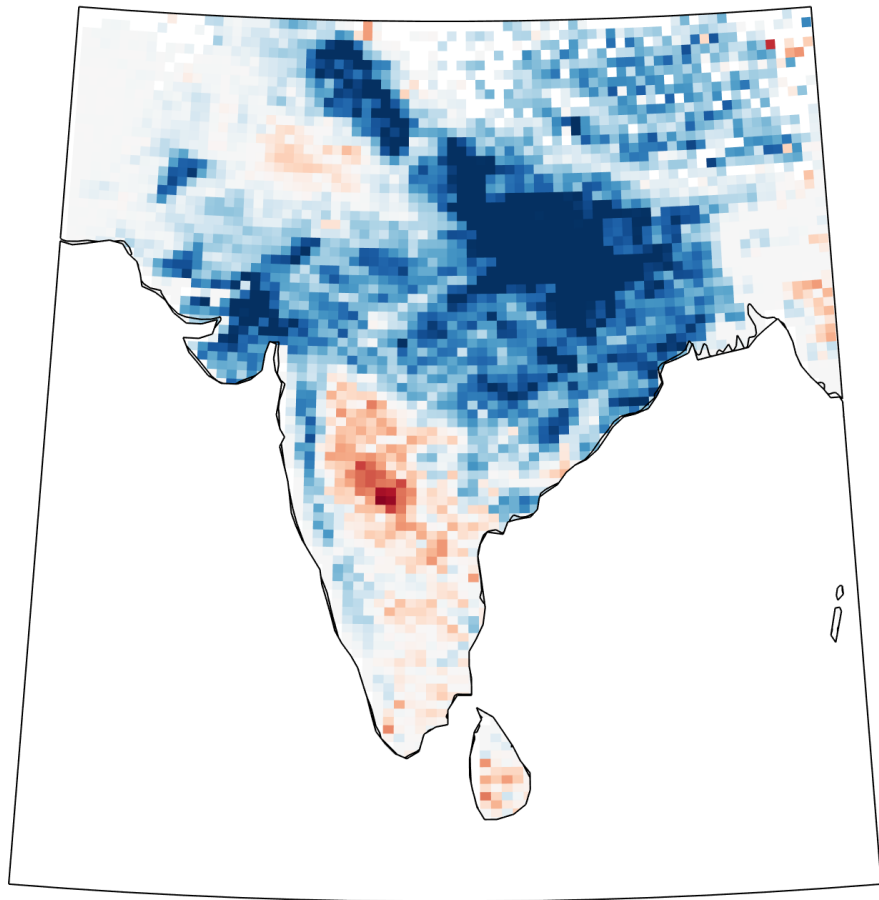
$\Delta \text{SNR (dB)}$

Amazon Rainforest

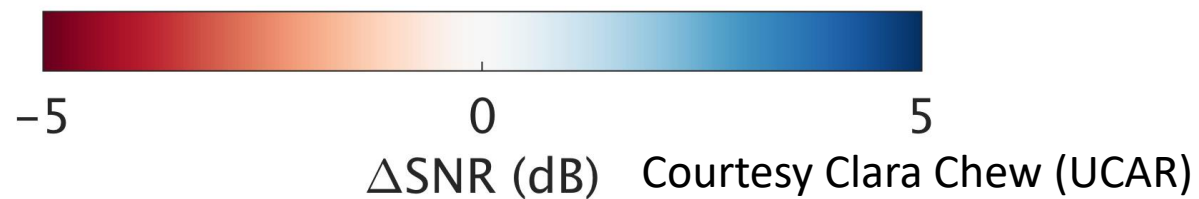
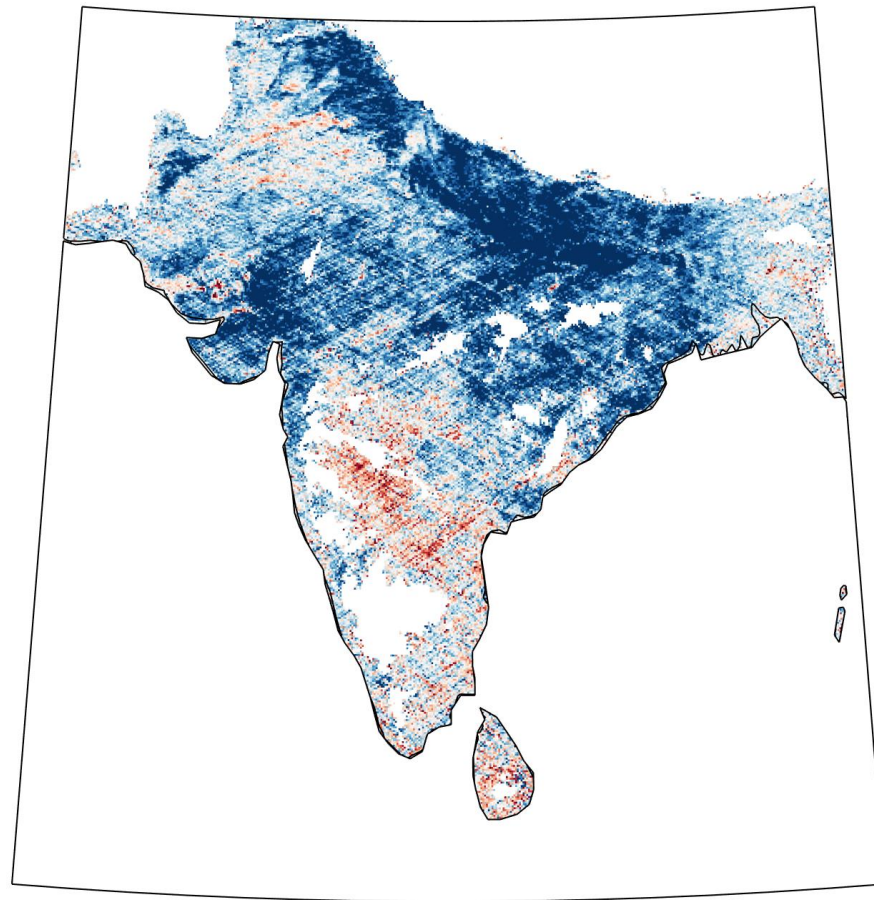
Courtesy Clara Chew (UCAR)

What's Happening in the GNSS-R Field?

SMAP Radiometer



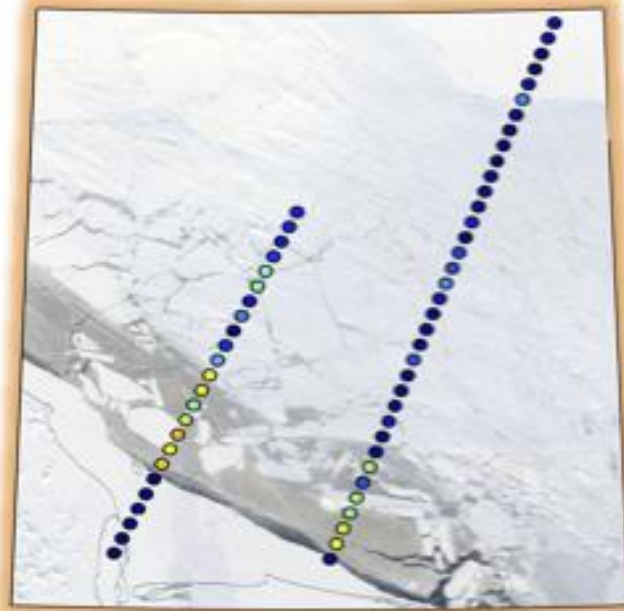
CyGNSS Data



Summary

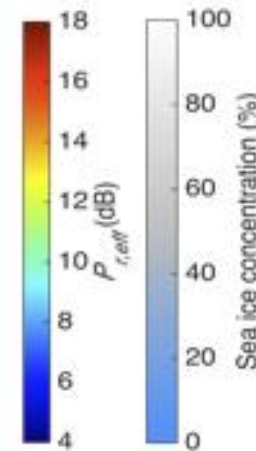
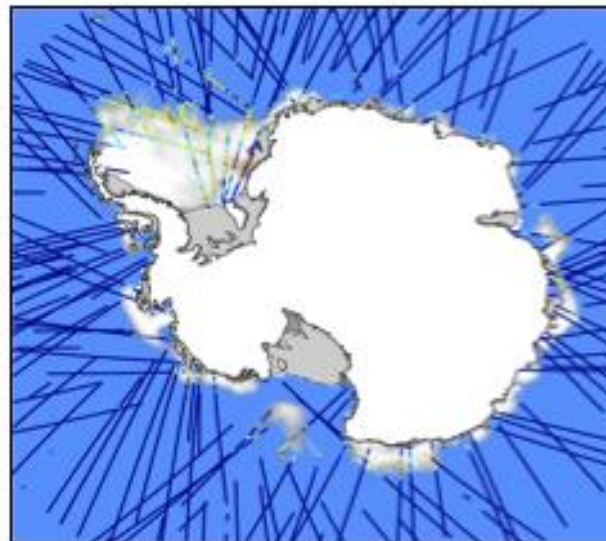
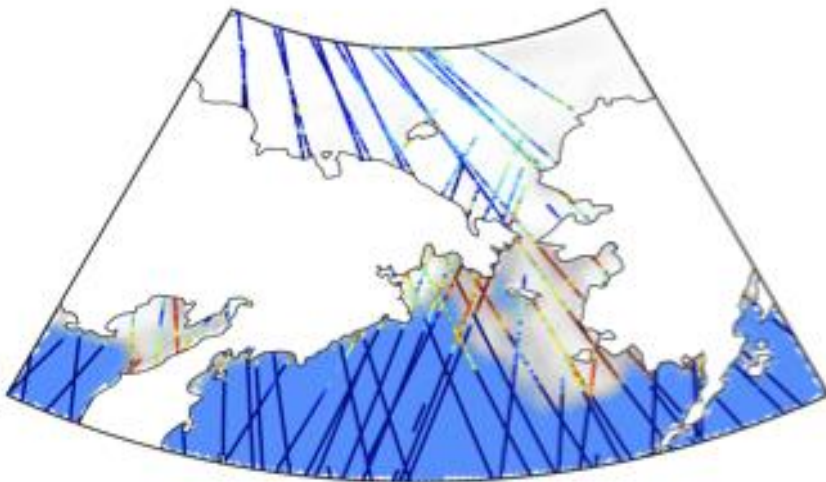
- GNSS-Reflectometry is a new Earth-remote sensing technique
- Beginning explosive growth: TDS-1 => CyGNSS
- Many unique advantages compared to other remote sensing techniques
 - High spatial/temporal coverage, forward scattering, RO-compatible, long-term SI-traceable signals
- Active research underway: Soil moisture, wetland extent, freeze-thaw state, sea ice extent, ocean altimetry

What's Happening in the GNSS-R Field?



TechDemoSat-1 Data

- Higher power over ice leads and polynyas
- Up to 10 dB increase
- Not seen in passive microwave



- Increased P on ice edges
- Highest P intermediate sea ice conditions

Courtesy Clara Chew (UCAR)